

TABLE 1.—Values of functions used in constructing the alignment diagram

T_w = water temperature	P_w = vap. press.	$x = \frac{P_w}{1+P_w}$	$\frac{T_w}{1+P_w}$	$y = \frac{.46 T_w}{1+P_w}$
0	4.58	0.8207	0	0
1	4.92	.8310	.1689	.0777
2	5.29	.8410	.3179	.1462
3	5.68	.8502	.4491	.2065
4	6.10	.8591	.5633	.2591
5	6.54	.8673	.6631	.3050
6	7.01	.8751	.7490	.3445
7	7.51	.8824	.8225	.3784
8	8.04	.8893	.8849	.4070
9	8.61	.8959	.9365	.4308
10	9.21	.9020	.9794	.4505
11	9.85	.9078	1.0138	.4663
12	10.52	.9131	1.0416	.4791
13	11.23	.9182	1.0629	.4889
14	11.99	.9230	1.0778	.4958
15	12.79	.9274	1.0877	.5003
16	13.64	.9316	1.0928	.5027
17	14.54	.9356	1.0939	.5032
18	15.49	.9393	1.0915	.5021
19	16.49	.9428	1.0863	.4997
20	17.55	.9460	1.0781	.4959
21	18.66	.9491	1.0681	.4913
22	19.84	.9520	1.0556	.4856
23	21.09	.9547	1.0411	.4789
24	22.40	.9572	1.0256	.4718
25	23.78	.9596	1.0088	.4640
26	25.23	.9618	.9912	.4560
27	26.77	.9639	.9722	.4472
28	28.38	.9659	.9530	.4384
29	30.08	.9678	.9330	.4292
30	31.86	.9695	.9129	.4199
31	33.74	.9712	.8923	.4104
32	35.70	.9727	.8719	.4011
33	37.78	.9742	.8509	.3914
34	39.95	.9755	.8302	.3819
35	42.23	.9768	.8096	.3724
36	44.62	.9780	.7891	.3630
37	47.13	.9792	.7687	.3536

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CERTAIN LIMITATIONS ON THE POSSIBLE VALUES OF THE RATIO OF HEAT LOSSES BY CONVECTION AND BY EVAPORATION AT A WATER SURFACE

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An alignment diagram has recently been prepared for the rapid computation of the ratio of the two quantities of heat leaving a water surface (see preceding paper). In addition to facilitating routine computations the diagram is useful as a rapid means of setting limits on the value that (R) can assume under certain specified conditions which alone are not sufficient for its exact evaluation. The explanation of this use of it will be postponed, however, until certain conclusions based on the general principles of thermodynamics shall have been drawn.

The atmosphere obtains most of its heat from the surface of the earth, and must therefore for the earth as a whole be colder than the earth's surface. Since a large part of the earth is covered with water, the water must in general be warmer than the air at the surface of contact. Although there may be isolated cases in which the air is warmer, they must be regarded as the exception rather than the rule. This deduction agrees with observation. It is, of course, understood that daily averages are referred to; at certain times of day the air is warmer almost anywhere.

Since negative evaporations from large bodies of water are rare it follows that from the meteorological standpoint positive values of (R) are more interesting than negative. Negative values of (R) combined with positive evaporations tend naturally to eliminate themselves because when (R) is negative the water is almost sure to be warming rapidly and (R) is thus in the act of becoming positive, unless very cold water is being supplied rapidly. The discussion will be limited therefore to positive values of ($T_w - T_a$).

Under these conditions evaporation rather than condensation is taking place. For any given air temperature and water temperature, then, (R) will be a maximum when wet and dry bulb temperatures are equal, because this condition makes (P_a) a maximum and therefore makes the denominator of the fraction a minimum, making the fraction as a whole a maximum. It follows that for the purpose of estimating (R_m), the maximum value of (R), (P_a) may be regarded as the pressure of saturated vapor at the temperature of the dry bulb.

For a given air temperature when wet and dry bulb are equal, (R) must increase as (T_w) decreases. This is evident from the fact that for saturated vapor $\frac{\Delta p}{\Delta t}$ decreases as the temperature (t) decreases and consequently reaches a minimum at the limit $\frac{dp}{dt}$. For any given air temperature, therefore, we may easily determine the greatest possible value of (R) by dividing .46 by $\frac{dp}{dt}$.

This derivative or the corresponding (R) may be computed in various ways:

(1) Directly from a table of saturated vapor pressures. This can be done most accurately by numerical differentiation, as described by von Sanden.

(2) From the well-known Clapeyron equation

$$L = t(v_1 - v_2) \frac{dp}{dt}$$

(3) By the aid of a variety of empirical equations. The following empirical equation was worked out by Doctor McEwen. It is based upon tabular values of saturated vapor pressures corresponding to a series of absolute temperatures, t .

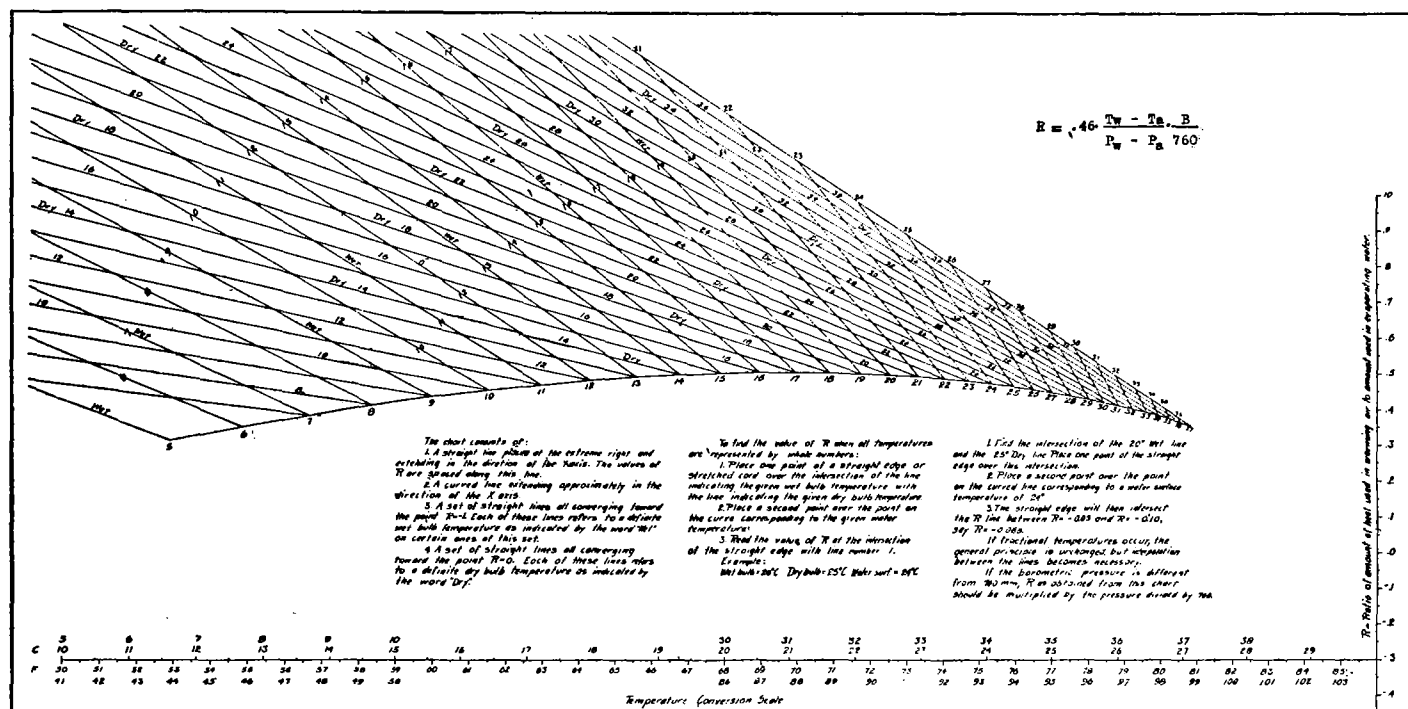
$$\frac{dp}{dt} = 0.48393 - 0.005570t + 0.0021111t^2 - 0.0000144664t^3$$

(4) The point at which the (R) locus of the alignment diagram is intersected by a line drawn tangent to the water-temperature locus at the point corresponding to the given air temperature represents the required value of (R).

The values of (R_m) obtained by these different methods are entered in Table 1. The relation between air temperature and (R_m) is shown by Figure 1. It is interest-

region, then the average evaporation over a long period of time is never greater than 100 per cent of the evaporating power of the net radiation.

Consequently, subject to the limitations specified, the evaporation must always lie between 42 per cent and 100 per cent of the evaporating power of the net radiation. It should be observed that these are extreme limits based on extreme temperatures and humidities. Actually the probability that the percentage will ever be as low as forty-two is extremely small, because the wet bulb is never higher than the dry bulb, but is nearly always lower; consequently the average must be appreciably lower. It can easily be seen from the alignment chart that, as the difference between wet and dry bulb increases, the value of (R) rapidly decreases.



ing to note that when the air temperature is 0°C . (R_m) is 1.38. Monthly air temperatures as low as 0°C . are usually not important from the standpoint of evaporation for two reasons:

(1) They occur only during the colder months and then only over a small part of the earth's surface.

(2) Under such conditions the vapor pressure of the water and, therefore, the evaporation rate are always small.

If we ignore all cases in which the air temperature is less than 0°C . and also those cases in which cold water is streaming through the volume under any particular area considered, we may say that the average evaporation from the area for a long period of time is never less than $\frac{1}{2.38} = 42$ per cent of the evaporating power¹ of the excess of incoming over outgoing radiation. If, on the other hand, we ignore negative values of (R) and those cases in which warm water is streaming through the

¹ This term is used by McEwen (1929, p. 244) to denote the evaporation equivalent of a definite quantity of energy, regardless of whether in the process considered the energy is all spent in evaporation or not. He applies the term to intensity of radiation penetrating the surface, signifying by it the depth of water which would be converted into vapor in unit time if all the penetrating radiant energy were dissipated by that process. The term is here applied to the excess of incoming over outgoing radiation. In the former case it is I/L , but in the present instance it is $(I-B)/L$.

TABLE 1.—Maximum values of (R) as computed by various methods

Temperature, centigrade	Numerical differentiating	Claudeyron equation	Empirical equation	Alignment diagram
5.....	1.00	1.00	0.91	0.98
6.....	.95		.88	.93
7.....	.89		.85	.91
8.....	.84		.83	.86
9.....	.79		.78	.76
10.....	.74	.736	.74	.73
11.....	.70		.70	.70
12.....	.67		.67	.67
13.....	.63		.63	.63
14.....	.59		.59	.59
15.....	.57	.552	.57	.57
16.....	.53		.53	.53
17.....	.50		.50	.49
18.....	.47		.47	.46
19.....	.44		.44	.43
20.....	.42	.418	.42	.42
21.....	.40		.40	.40
22.....	.38		.38	.37
23.....	.36		.36	.34
24.....	.34		.34	.34
25.....	.32	.318	.32	.32
26.....	.31		.31	.31
27.....	.29		.29	.28
28.....	.28		.28	.27
29.....	.27		.27	.26
30.....	.25	.244	.25	.25

Richardson, Kimball, Angot, Abbot, and others have conducted investigations regarding the relation between the intensity of solar radiation at the outer limits of the earth's atmosphere and the intensity at the earth's surface. Although the problem is complex, some conclusions of great value have been drawn. It is probable that these conclusions, together with the limits which can be set on the values of (R), will be of great value in connection with theories of climatic change, particularly glaciation.

The kind interest which Doctor McEwen of this institution has taken in the preparation of this paper, and also the valuable suggestions he has offered, are gratefully acknowledged.

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CHICAGO'S GREATEST SNOWSTORM, MARCH 25-26, 1930

By OWEN T. LAY

[Weather Bureau office, Chicago, Ill., April 14, 1930]

The greatest snowstorm in the history of Chicago occurred on March 25-26, 1930. The total amount of snow was 19.2 inches (average depth) at the Weather Bureau observatory at the University of Chicago. The snow was badly drifted by the wind, and drifts 4 to 5 feet deep were to be found in all portions of the city. The storm continued without interruption for 43 hours and 45 minutes. The depth of 19.2 inches exceeded by 4.3 inches the total snowfall from any other single storm at Chicago, the previous record being 14.9 inches on January 6-7, 1918.

GENERAL METEOROLOGICAL CONDITIONS

On the evening of March 22, 1930, a barometric depression covered most of the Rocky Mountain region and Great Plains. By 7 a. m. on the 23d it had deepened somewhat and moved eastward, there then being two centers of lowest pressure, 29.60 inches in eastern North Dakota and 29.62 inches in central Iowa. Snow was falling over Wisconsin and eastern Minnesota. Within the next 12 hours there was little change in the intensity of the storm and both centers moved slowly east-southeastward, with rain in Illinois and southern Wisconsin and mostly cloudy weather thence northwestward.

By the morning of the 24th the northern center had practically disappeared and the southern center had moved from southeastern Iowa to west-central Indiana, with little change in intensity. During the next 12 hours, ending at 7 p. m. on the 24th, the center had advanced to extreme eastern Ohio but appeared only as a loop in the isobar, while a new center had apparently developed over southeastern Missouri and advanced to southern Indiana.

During the next 12 hours, ending at 7 a. m. on the 25th, the center over southern Indiana remained practically stationary with an increase in intensity from 29.54 inches to 29.28 inches, while the eastern loop had disappeared. By evening the main center of the storm had advanced to western Lake Ontario, but another center was left over east-central Indiana. By the morning of the 26th the eastern center had advanced to extreme southern Quebec, Montreal, 29.04 inches, and the western center had moved north-northeastward to the Georgian Bay region, Parry Sound, 28.98 inches, and by the night of the 26th the eastern center had practically disappeared and the western center continued to move north-northeastward, Doucet, Quebec, 29.10 inches.

The heaviest snow at Chicago occurred on the 25th with strong northeast winds from off Lake Michigan. These winds persisted throughout the 25th up to about

6 p. m., ninetieth meridian time, when they backed to northwest and continued from that direction until 8:55 p. m. of the 26th. Gust velocities on the 25th ranged from 35 to 50 miles an hour from the northeast. During this time the storm center was over central and southern Indiana where it remained practically stationary for about 24 hours. That fact remains to be explained; apparently it was due to the advance from the west of a fresh fall in the barometer that sent the surface pressure down to 29.28 inches, and naturally caused strong northeast winds to continue to blow over the southern end of Lake Michigan with the results described herein.

LOCAL CHARACTERISTICS OF THE STORM

Starting with rain on the 24th, the temperature fell slowly and the rain first became mixed with sleet, then changed to snow. The air became filled with large snowflakes, and the wet character of the snow at first, in connection with high northeast winds, caused it to adhere to automobile windshields, windows, and buildings. Many accidents resulted during this period of poor visibility, which extended through most of the 25th.

The lateness of the season added an element of surprise and unpreparedness. Few automobiles were equipped with chains, and transportation organizations were not in readiness to combat the storm.

EFFECTS

The continued stalling of automobiles and trucks on car tracks made the constant operation of snow plows and street cars difficult or even impossible. Furthermore, automobile and truck traffic early in the storm served to pack the wet snow into soft ice that later had to be removed from street-car tracks by the use of picks and shovels. Many automobiles were abandoned in the streets. By noon on the 25th surface car service was practically at a standstill, suburban trains were moving with difficulty, and deliveries by motor vehicle had almost ceased. This imposed an extra burden upon the elevated lines, and that service was slowed up greatly because of the great crowds at the stations and on the trains.

Workers experienced much difficulty in reaching their places of employment and in returning to their homes on the 25th and 26th, and the down-town hotels were crowded. Many places of business closed early to enable their employees to reach their homes. In many cases those who came to work or returned home floundered through the snow for several miles to reach transportation that was moving on elevated tracks.